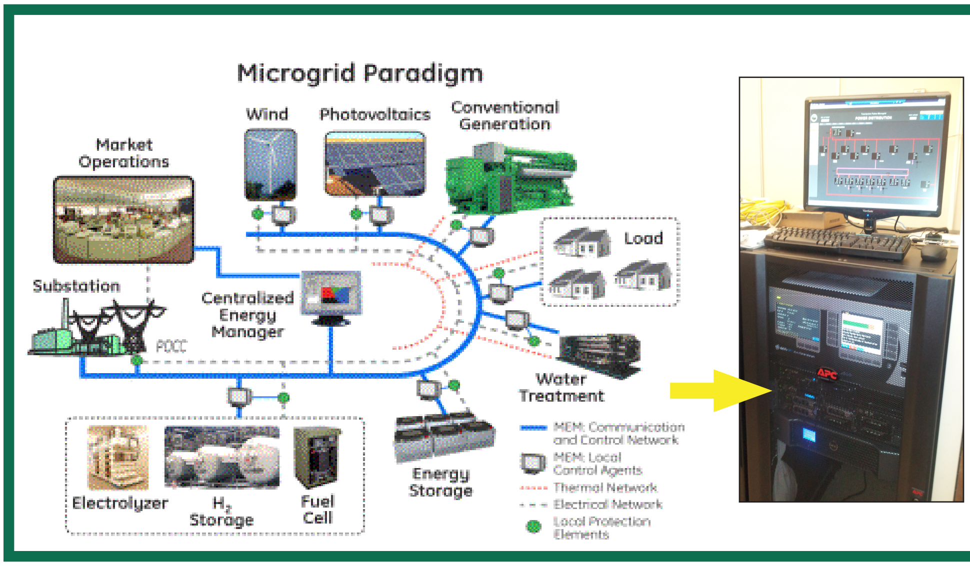
ESTCP
Cost and Performance Report

(EW-200937)



Smart Microgrid Energy Management Controls for Improved Energy Efficiency and Renewables Integration at DoD Installations

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TABLE OF CONTENTS

Page

TABLE OF CONTENTS (continued)

LIST OF FIGURES

Page

LIST OF TABLES

Page

ACRONYMS AND ABBREVIATIONS

AIRR	annualized internal rate of return
BEM	building energy management
BLCC	Building Life-cycle cost
CCS	central control system
CES	computerized electric systems
CHP	combined heat and power
Co-Gen	co-generation plant
DER	distributed energy resource
DG	Distributed Generation
DoD	U.S. Department of Defense
EMCS	energy management control system
ESTCP	Environmental Security Technology Certification Program
FCC	Federal Communication Commission
GHG	greenhouse gas
GHz	giga hertz
GR	Global Research
GW	gig watts
HMI	Human Machine Interface
HTHW	high temperature hot water
HVAC	heating, ventilation, and air-conditioning
IED	intelligent electronic device
IEEE	Institute of Electrical and Electronics Engineers
JCI	Johnson Controls, Inc.
km	kilometer
kWh	kilowatt hour
LCC	Life-cycle Cost
MCAGCC	Marine Corps Air Ground Combat Center
MCS	microgrid control system
MGC	Microgrid Control
MW	MegaWatt
NAE	network automation engine
NG	natural gas

ACRONYMS AND ABBREVIATIONS (continued)

NIST	National Institute of Standards and Technology
PV	photovoltaic
PWD	Public Works Department
RC4-128	128 bit Rivest Cipher 4
SCE	Southern California Edison
SIR	savings to investment ratio
UR90+	Universal Relay 90+
USEPA	U.S. Environmental Protection Agency
VAr	volts-amps-reactive
Wi-MAX	Worldwide Interoperability for Microwave Access

ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

As the title suggests, the project was aimed at developing microgrid energy management controls for improved energy efficiency and renewable integration at the U.S. Department of Defense (DoD) installations. The microgrid control system (MCS) demonstrated in this project is designed to manage and control the complicated interactions among heat and electrical power generation, power demand, energy storage, and power distribution and delivery. The advanced control and optimization functions include optimal dispatch of distributed energy resources (DER) (including renewable and energy storage), initial capability of load management during grid connected or islanded operation, and energy efficiency optimization by simultaneously controlling DER for maximum efficiency and managing the major electrical loads. The important technology contributions to improving energy efficiency and increasing energy security are (1) the ability to include various assets such as renewables, combined heat and power units, electrical and thermal storage, and controllable loads as energy management resources; (2) the ability to include future predicted values of loads, renewable generation, and fuel and electricity prices in the optimization process; (3) the ability to automatically commit/de-commit DERs as needed; and (4) the use of a predictive control strategy to address renewable generation intermittency. The optimal dispatch problem is suitably formulated so that it can be solved using computationally efficient and robust optimization algorithms.

The current state-of-the-art power grid includes minimal renewable or clean energy, no intelligent distribution, minimal or no energy storage, ad hoc dispatch, uncontrolled load demands, and excessive distribution losses. Microgrids are envisioned as local power networks that utilize DER and manage the local energy supply and demand. While microgrids would typically operate connected to the national bulk power transmission and distribution system, they would have the ability to disconnect from the grid and function in "island mode" when necessary.

Implementation of this technology is expected to lead to improved energy efficiency and reduced fossil fuel use, increased energy security and power system reliability that enables continuous military base operation, and reduced carbon footprint and greenhouse gas emissions. The technology is scalable (i.e., it can handle small [several hundred kilowatt] to large [several tens of megawatts] microgrids) and is transferrable to multiple DoD installations that contain various types of renewable resources.

The objective of this project is to demonstrate advanced microgrid control technologies capable of improving energy efficiency, expanding use of renewables, and increasing energy security for the DoD. The MCS technologies developed for this project is analyzed via a field demonstration at the selected DoD installation site as well as multiple laboratory tests with the field data, to validate the technology's performance and expected operational costs. The ability of the technology to improve the energy efficiency, enable renewable integration, increase energy security, and reduce operational cost is evaluated by comparing system performance to a baseline of the Twentynine Palms site operation. The goal is to enable this promising technology to receive regulatory and end user acceptance and be fielded and commercialized more rapidly.

Table 1 in Section 3 shows the performance objectives and the outcomes from demonstration and testing. During unit commitment and optimal dispatch, 100% of the renewables were used all the time. By adjusting the heat versus electrical outputs of the combined heat and power (CHP), 2-4% efficiency is possible in a conservative estimate. In certain situations and definitely with more assets larger increase is possible. The project also demonstrated that a sizable amount of electric load can be dropped instantly by managing the building loads. Depending on the number of buildings participating, a 10% reduction of aggregated loads is possible in a few seconds to 10-15 minutes timescale without tripping the whole building or sacrificing too much comfort. In terms of qualitative objectives, favorable response is obtained from the microgrid operators. The project received good feedback during presentations at the conferences with utility representatives. Informal discussions with the Base personnel were very favorable. The key testimony was their desire to expand the technology for rest of the Base.

It is found that with current configuration of minimal assets, a Savings to Investment Ratio (SIR) of 6.6 and Annualized Internal Rate of Return (AIRR) of 13% is achievable. These can be increased to SIR of 11-12 and AIRR of 16% with a larger number of microgrid assets. Building load management helps in energy surety but it does not yield high AIRR because communication and other controls may need to be put in place, which will add to the cost. Optimal dispatch with load management however yields a reasonable SIR of around 4% with AIRR of 11%. Using all available renewables for optimal dispatch leads to lesser CO_2, SO_2 and NO_x emissions. A savings of around 21,410 tonnes of CO_2 emissions, 165 tonnes of SO_2 emissions and 45 tonnes of NO_x emissions is expected per year due to complete utilization of available renewable assets.

This project had a relatively seamless implementation and system integration during the demonstration phase due to excellent camaraderie and support provided by the Base engineers and members of their Energy Service Provider (Johnson Controls, Inc.). Without their cooperation and teaMWork, this project would not have reached this stage of success. There are a few lessons learned that are discussed in this report, which can aid future implementation of the technology. Some of these lessons learned include: the inability to export excess power generated by its DERs to the outer grid, lack of variable pricing schemes, inability to do continuous set-point control of diesel gensets due to U.S. Environmental Protection Agency (USEPA) regulations, unavailability of state-of-the-art solar inverters, and non-operational assets like the fuel cell etc.

The method by which the technology will be transitioned to the DoD end user(s) involves the actual usage of the MCS on the base's identified microgrid via GE Digital Energy (microgrid controller and volts-amps-reactive [VAr] control) and GE Intelligent Platforms (supervisory controller, the Human Machine Interface [HMI], the Building Energy Management [BEM], and certified network communications) hardware and software tailored for the Twentynine Palms operation. GE can specify the technology transfer method for the appropriate audience. The GE proposed hardware and software initially developed for Twentynine Palms can be utilized for additional DoD bases with limited modifications. GE has some relationships with other DoD bases and will work with DoD's Environmental Security Technology Certification Program (ESTCP) to identify other DoD bases for follow-on installations.

1.0 INTRODUCTION

The current state-of-the-art power grid includes minimal renewable or clean energy, no intelligent distribution, minimal or no energy storage, ad hoc dispatch, uncontrolled load demands, and excessive distribution losses. Microgrids are envisioned as local power networks that utilize distributed energy resources (DER) and manage the local energy supply and demand. While microgrids would typically operate connected to the national bulk power transmission and distribution system, they would have the ability to disconnect from the grid and function in “island mode” when necessary.

1.1 BACKGROUND

The microgrid control system (MCS) to be demonstrated is designed to manage and control the complicated interactions among heat and electrical power generation, power demand, energy storage, and power distribution and delivery. The MCS also can optimize energy usage and offers energy security by maintaining photovoltaic (PV) cells and managing backup power operation for critical loads in the event the microgrid is disconnected from the bulk grid (or islanded). The advanced control and optimization functions include optimal dispatch of distributed energy resources or DERs (including renewable and energy storage), initial capability of load management during grid connected or islanded operation, and energy efficiency optimization by simultaneously controlling DERs for maximum efficiency and managing the major electrical loads. The important technology contributions to improving energy efficiency and increasing energy security are: (1) the ability to include various assets such as renewables, combined heat and power units, electrical and thermal storage, and controllable loads as energy management resources; (2) the ability to include future predicted values of loads, renewable generation, and fuel and electricity prices in the optimization process; (3) the ability to automatically commit/un-commit DER as needed; and (4) the use of a predictive control strategy to address renewable generation intermittency. The optimal dispatch problem is suitably formulated so that it can be solved using computationally efficient and robust optimization algorithms.

Implementation of this technology is expected to lead to improved energy efficiency and reduced fossil fuel use, increased energy security and power system reliability that enables continuous military base operation, and reduced carbon footprint and carbon dioxide emissions. The technology is scalable (i.e., it can handle small [several hundred kilowatt] to large [several tens of megawatts] microgrids) and is transferrable to multiple Department of Defense (DoD) installations that contain various types of renewable resources.

1.2 OBJECTIVE OF THE DEMONSTRATION

The objective of this project is to demonstrate advanced microgrid control technologies capable of improving energy efficiency, expanding use of renewables, and increasing energy security for the DoD. The MCS technologies developed for this project is analyzed via a field demonstration at a selected DoD installation site, as well as multiple laboratory tests with the field data to validate the technology’s performance and expected operational costs. The ability of the technology to improve the energy efficiency/life cycle, increase energy security, and reduce cost is evaluated by comparing system performance to a baseline of the Twentynine Palms site

operation. The goal is to enable this promising technology to receive regulatory and end user acceptance and be fielded and commercialized more rapidly.

The demonstrations conducted met all the stated objectives. During unit commitment and optimal dispatch, 100% of the renewables were used all the time. This was measured by making sure the energy cost output from the controller, with and without renewables, under same load conditions. By adjusting the heat versus electrical outputs of the combined heat and power (CHP), 2-4% efficiency is possible in a conservative estimate. This is measured by the cost difference noted from the microgrid controller in multiple tests with varying electricity to heat ratios. In certain situations and definitely with more assets a larger increase is possible. The project also demonstrated that a sizable amount of electric load can be dropped instantly by managing the building loads. Depending on the number of buildings participating, 10% of reduction of aggregated loads is possible in few seconds to 10-15 minutes timescale without tripping the whole building or sacrificing too much comfort. This was measured by capturing traces of building load with time as shown in section 6. In terms of qualitative objectives, favorable response is obtained from the microgrid operators. The project received good feedback during presentations at the conferences with utility representatives. Informal discussions with the Base personnel were very favorable. The key testimony was their desire to expand the technology for rest of the Base.

1.3 REGULATORY DRIVERS

The existing regulations, Executive Orders, and DoD directives have resulted in a need for a new microgrid control technology includes:

1. Energy Policy Act of 2005;
2. Executive Order 13423;
3. Energy Independence and Security Act of 2007;
4. Secretary of the Navy mandates;
5. State mandates; and
6. Institute of Electrical and Electronics Engineers (IEEE) 1547-2003: IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems.

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY OVERVIEW

Microgrids are local power systems that use DER to manage the local energy supply and demand. They increase the viability of DER in the bulk grid by aggregating them into clusters with better grid stability properties than a multiplicity of standalone generators. They have the ability to separate themselves from the bulk grid and function in island mode; therefore, they have the potential to enhance grid resiliency, customer reliability and security by reducing susceptibility to faults and disturbances. At a high level, the interest in microgrid power systems is driven by a growing desire to locate DER closer to load centers. This interest in DER is being fuelled by a number of factors, including:

- Transmission congestion, and problems with siting new transmission lines, make it appealing to site DER in distribution systems to cope with new loads;
- Utilization of DER can help utilities defer investments in generation and transmission capacity;
- DER have the potential to offer increased total energy efficiency when used with CHP or combined cooling heat and power, and can reduce energy costs;
- Appropriately integrated DER can improve power availability and quality;
- Distributed systems offer potential security advantages over centralized systems;
- DER promote fuel diversity (e.g., biomass, landfill gas, flare gas, wind, solar) and can reduce overall energy price volatility;
- Renewable DER such as wind and solar PV cells provide emissions-free energy; and
- DER offer a quicker solution with regards to installation, lead time and siting relative to centralized generation.

While all of these benefits make DER attractive, the primary concern at the utility level is the system operation and protection issues associated with the existence of a large number of independent power producing assets operating without coordination. Microgrids offer a framework that resolves this concern through the aggregation of DER into well-behaved entities that can be dispatched by the utilities, as shown in Figure 1. The capability for microgrids to disconnect from the bulk grid to operate in an island mode will provide the end-users with better availability than DER alone. DERs within the microgrid are equipped with local controllers that regulate real power, reactive power, frequency, and/or voltage. Intelligent electronic devices (IED) located elsewhere in the microgrid provide system loading, voltage, and frequency information and carry out switching operations. The MCS implements a centralized, supervisory control layer. It polls all resources, executes central control algorithms, and sends resulting control commands back to each resource. The MCS is built on a utility-grade, embedded processor platform, called U90Plus. A microgrid network provides the communications infrastructure which uses both Ethernet and Wireless media. Ethernet is easily extendable and supports multiple protocols, accommodating a broad range of devices and services. The Ethernet

network supports fiber-optic cabling, which is immune to ground potential differences and transients generated by faults or switching events. Remote resources are also integrated into the microgrid network using wireless network currently existing in the Base. These devices (Ubiquity radios) incorporate frequency hopping and spread spectrum radio for high reliability. Data is encrypted using 128 bit Rivest Cipher 4 (RC4-128) with automatic key rotation. Ubiquity radios support distances of up to 10 kilometers (km). Key features of this architecture include:

- Support of centralized and distributed approaches
- Adaptability of a broad range of energy technologies
- Flexibility to accommodate current and future applications

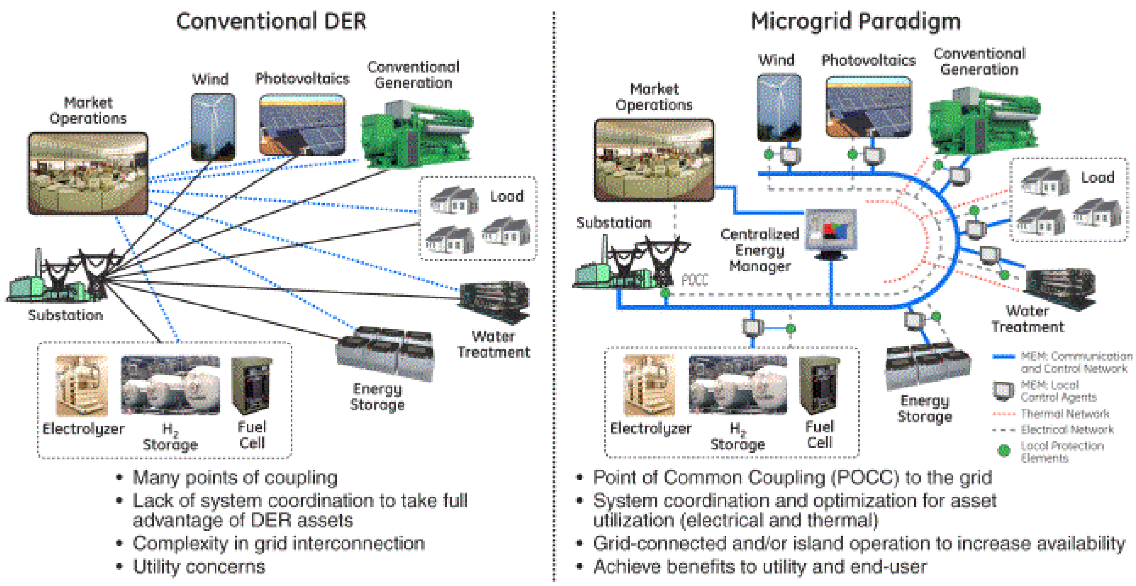

Figure 1. Microgrid Paradigm.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The goals of this project were to deliver: 1) an advanced MCS with enhanced added features and functions including optimal dispatch of DER, and load/energy management; and 2) a field demonstration system at a suitable DoD installation and Twentynine Palms was the site for the demonstration. The expected benefits of the project are improved energy efficiency, increased energy surety enabling continuous operation of critical assets, and reduced carbon footprint and CO_2 emissions. These goals were met (as described in Section 6), with several successful demonstrations at the Base as well as careful testing conducted at the laboratory of GE Global Research. Based on these results, we believe that the technology is scalable to all DoD installations that have a good diversity of energy resources like CHPs, renewables, energy storage, etc.

The benefits of the technology are tied to amount of DER available in a given microgrid. For grid-connected microgrids with limited number of DER, the benefits of optimal dispatch will be relatively small. Also, if this microgrid is connected to a stable utility grid that provides high

reliability, then the microgrid will not need too many islanding operations. On the other side, another limitation to demonstrate benefits can be seen if the available DER are of much higher capacity than the available controllable loads. In this case load management is not needed during islanding as the DER can easily support all of these loads.

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3.0 PERFORMANCE OBJECTIVES

The performance objectives presented in this section define the specific means by which this project met its goals. Data collected during the demonstration will provide the information necessary to assess the effectiveness of the various strategies used. There are three high-level quantitative benefits that the performance objectives provide:

1. Increased renewable energy usage and reduced greenhouse gas (GHG) emissions;
2. Increased energy efficiency; and
3. Increased energy surety.

This demonstration will also directly impact two qualitative objectives:

1. Regulatory and end user acceptance; and
2. User satisfaction.

3.1 SUMMARY OF PERFORMANCE OBJECTIVES

The summary of performance objectives is shown in Table 1.

Table 1. Performance objectives.

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives				
Increased renewable energy usage and reduced fossil fuel usage	Ability to optimize more renewables and natural gas (NG) based resource.	Estimate potential displacement of fossil fuel based generation by using renewables and other NG based DERs. Calculate GHG emissions reduced.	Capability to use and optimize up to 100% of emission-free energy resources.	As described by the results in Section 6, 100% of the renewables were used all the time.
Increased energy efficiency	Operate DER and boilers at their highest power factor and efficiency regions.	Power time histories – imported power, generated electrical power by the DERs, generated thermal power; NG and boiler usage.	Compared using multiple DER and boilers used to meet the same demand, microgrid controller can show up to 2-3% efficiency over the year improvements in a microgrid with a few boilers and one CHP. This number is expected to increase to 10-15% with more CHPs and energy storage.	As discussed in the results of Section 6, adjusting the heat versus electrical outputs of the CHP, 2-4% efficiency is possible in a conservative estimate. In certain situations and definitely with more assets much bigger increase is possible.

Table 1. Performance objectives (continued)**.**

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives (continued)				
Increased energy surety	Percentage of extra critical loads that can be served in absence of grid power.	Percentage of non-critical load reduction (e.g., 2 degree increase in thermostat settings) in building loads.	Based on the availability of non-critical loads during the hours of islanding, the target is to serve 10% of extra critical loads and thereby provide nearly 100% longer service to this 10% load assuming that Cogen capability remaining same all through the islanded operation.	As discussed in the results of Section 6, a sizable amount of electric load can be dropped instantly by managing the building loads. Depending on the number of buildings participating, 10% of reduction of aggregated loads is possible in few seconds to 10-15 minutes timescale without tripping the whole building or sacrificing too much comfort.
Qualitative Performance Objectives				
Regulatory and end user acceptance	Degree of acceptance.	During training and demonstration show how microgrid can be a "win-win" proposition between regulators and end-users.	Favorable response from the microgrid operators as well as their interactions with the utility/regulators.	As described in Section 6, a favorable response is obtained from the microgrid operators. Also, the project received good feedback during presentations at the conferences with utility representatives.
User satisfaction	Degree of favorability	Informal interviews	Favorable opinions and constructive comments expressed by stakeholders.	Informal discussions with the Base personnel were very favorable. The key testimony was their desire to expand the technology for rest of the Base.

3.2 PERFORMANCE OBJECTIVES DESCRIPTIONS

3.2.1 Increased Energy Efficiency

This measure quantifies the effectiveness of the MCS to manage electrical and thermal energy within the microgrid. This is expected to provide higher benefits than managing the electrical energy all by itself, especially when one primary distributed energy resource is a CHP unit which can generate both electricity and heat. To determine the efficiency improvement, the data requirements include: the NG consumption by the co-generation plant (Co-Gen) as well as the boilers of the high temperature hot water (HTHW) system, the active and reactive power produced by the Co-Gen, the input/output temperatures and flow rates within the HTHW system.

3.2.2 Increased Energy Surety

The project will demonstrate ablility to control loads from the centralized microgrid controls. Appropriate buildings will be chosen to demonstrate that non-critical loads in the building can be

either completely turned off (e.g., unnecessary lighting) or turned down (e.g., by increasing the thermostat settings on a hot summer day without sacrificing comfort). Load shedding in this project shall consist of building compressor settings and opening and closing breakers at individual buildings. Since in any operational military facility, it is unlikely that access will be given to all the loads. However once the load shedding capability has been demonstrated in a few buildings, it can be replicated for any other building loads. The project targets to demonstrate that a sizable amount of electric load can be dropped instantly by managing the building loads. Depending on the number of buildings participating, 10% of reduction of aggregated loads is possible in few seconds to 10-15 minutes timescale without tripping the whole building or sacrificing too much comfort.

3.2.3 Increased Renewable Energy Usage and Reduced Fossil Fuel Usage

Operability of renewables will be given the highest priority in the microgrid objective function. Before optimizing other distributed resources, renewable resources such as PV will get the highest priority in the Unit Commitment. This will be true even during Islanded mode operations. While it is hard to quantify the "maximum utilization" or renewables since it depends on available sunlight, the project will estimate potential displacement of fossil fuel based generation by using renewables and other natural gas (NG) based distributed generations (DG) and calculate GHG emissions reduced. Experiments were conducted (first in the laboratory) about the effect of increasing the renewable and Cogen to cover almost 100% of the loads and thus demonstrate the capability of full displacement of fossil fuel-based generation from the grid.

3.2.4 User Satisfaction

Reduced Operator involvement during operations is a metric that measures the effectiveness of the MCS to manage the complex interaction of electrical and thermal energy within the microgrid. The MCS will include an Operator event log, which will enable the capture of the interaction of the Operator with the MCS. The system operators will also have the flexibility of keeping some assets under manual control. User satisfaction needs to be guaranteed by co-locating the user interfaces through bigger visual inputs and seamless operation from one screen to another. Informal interviews of the operators will be conducted periodically and appropriate actions will be taken based on their suggestions.

3.2.5 Regulatory and End-User Acceptance

Regulatory and end-user acceptance are always key challenges for any new technology and microgrid is no exception. During the training and demonstration phase, this project aims to show how microgrid can be a "win-win" proposition between regulators and end-users. The team will organize series of demonstrations and outreach events, participate in conferences and workshops and through their interactions with the utility/regulators and other key stakeholders for microgrids in the DoD sector, influence regulatory and end-user acceptance.

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4.0 SITE/FACILITY DESCRIPTION

The MCS is demonstrated at Twentynine Palms Marine Corps Air Ground Combat Center (MCAGCC) in California, the largest marine base in the country.

4.1 SITE/FACILITY LOCATION, OPERATIONS AND CONDITIONS

Among the candidate sites considered, Twentynine Palms ranked the highest and was therefore selected as the site for the demonstration. Twentynine Palms has 7 acres of solar PV cells that total more than one megawatt (MW), as well as a gas-fired cogeneration plant in excess of 7 MW. In the future, additional solar PV, fuel cells and advanced energy storage systems may also be added to the marine base's on-site resource mix. The single line diagram of the Twentynine Palms power distribution system and a picture of the base are shown in Figure 2. It is connected with the Southern California Edison (SCE) utility grid at the Ocotillo substation. Some parts of the Cogen Facility under Substation AA is used for demonstrating the microgrid.

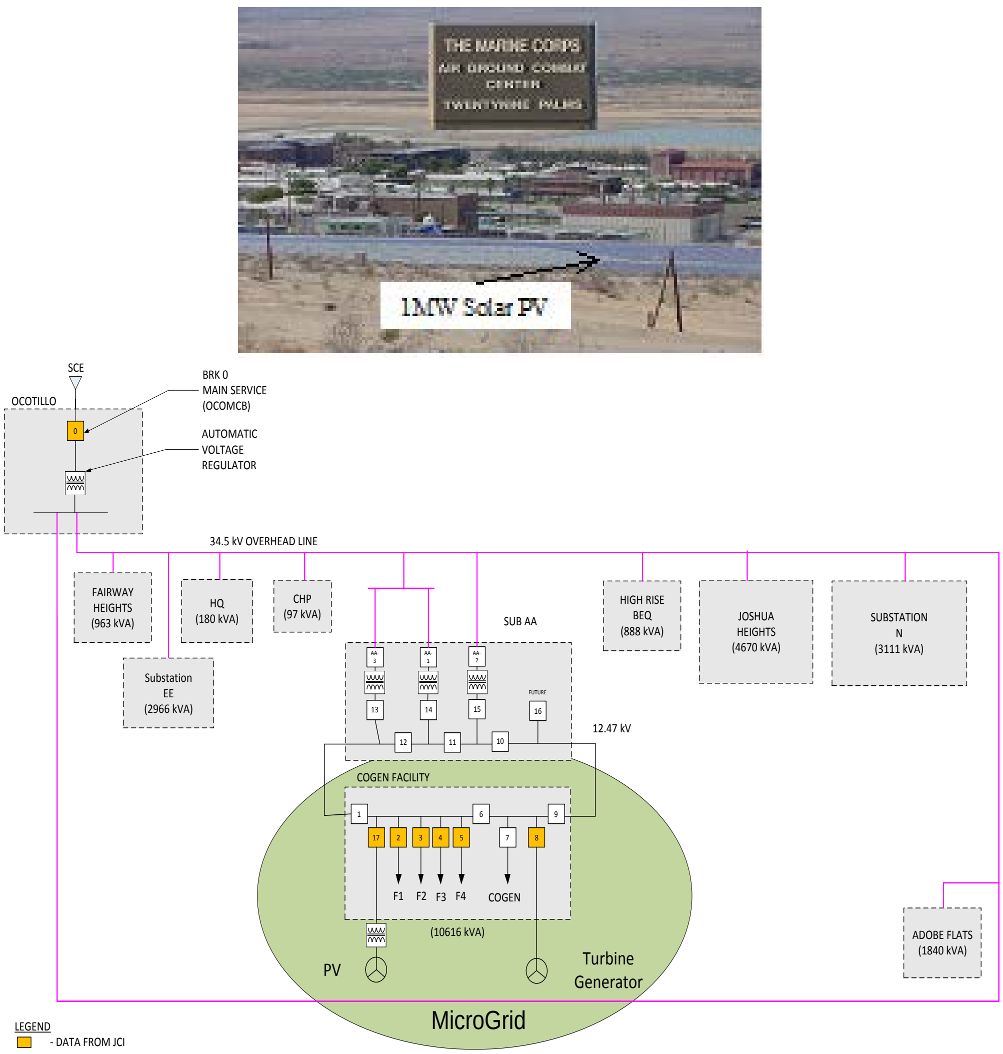

Figure 2. Twentynine Palms Marine Corps site and the electrical single line diagram.

Twentynine Palms has an installed 7.2 MW gas turbine co-gen facility that supports base electric and high temperature hot water loads. It has diesel gensets and will have fuel cell systems onsite as well. It also currently has a one MW solar PV cells system with plans to add additional MW in coming years. The substations that power the base are being upgraded with automation equipment, smart meters, and sensor devices. The Twentynine Palms base was chosen because of the variety of DER resources available as well as planned for the near future. It was also selected because of its planned active participation in the deployment of smart grid technology. This was an ideal site to demonstrate the MCS technologies developed at GE.

The following is a list of distributed generation assets available at the Base:

1. One CHP of 7.2 MW capacity. Two more CHPs were commissioned and were ready at beginning of 2013.
2. One PV plant of 1 MW rating. There were distributed PV modules throughout the base (rooftops, parking lots, etc.), which were currently not used in the energy management but were estimated to be about 2-3 MW total capacity.
3. Diesel gensets in about 35-40 buildings with a total capacity of around 4 MW. However, these units were used only for emergency purpose and can’t be used for regular microgrid operations due to environmental constraints from the U.S. Environmental Protection Agency (USEPA).
4. A fuel cell unit, currently non-functional.
5. In 2013, based on another Environmental Security Technology Certification Program (ESTCP) funded project, an energy storage system of 1 MW, 576 kilowatt hour (kWh) rating was installed.
6. There were three main boilers available to provide the bulk of heating loads at the Base.

4.2 SITE/FACILITY IMPLEMENTATION CRITERIA

The objective of the demonstration at a DoD installation site was to further validate, refine, and transition the microgrid control and building energy management technologies to commercialization. The demonstration allowed the developers to collect real-time data and feedback, and identify gaps and shortfalls for further improvement and next generation design. It also gave users first-hand experience in using and interfacing with the new technology and product. GE worked with the DoD assigned liaison in selecting the site for demonstration. A subset of the criteria used for site selection includes:

- Government furnished equipment;
- DER resources (solar PV, diesel genset, fuel cell and CHP) available now and plans for future additions;
- Availability or plan for energy storage;
- Consumer acceptance and participation in smart grid technology;

- Controllable building loads such as heating, ventilation, and air-conditioning (HVAC) and chiller;
- Electricity cost and plans to incorporate variable electricity pricing;
- Advanced metering infrastructure and Ethernet communication infrastructure;
- Capability or flexibility of upgrading legacy generator control systems;
- Geographical location and climate of the site; and
- Necessary funding available to implement the balance of the project.

All the existing and planned resources were evaluated and taken into consideration in the site selection process. A number of candidate sites were identified then evaluated against the criteria. A Pugh analysis was used to rank the sites quantitatively. Each criterion was first assigned a weight based on its importance to the technology and the demonstration. Each site was then compared against a chosen baseline/reference site. A weighted score was then calculated. The ones with highest scores were the leading candidate sites.

4.3 SITE-RELATED PERMITS AND REGULATIONS

Discussions with site personnel have been, and continue to be, held. Per those conversations, the current status regarding permits and regulations are:

- ***Federal Communication Commission (FCC) permits for 3.65 Giga Hertz (GHz) Worldwide Interoperability for Microwave Access (WiMAX) radios:*** The site is responsible for acquiring these.
- ***Other hardware installations:*** The site is responsible for acquiring these.
- ***Software installations:*** Discussions are ongoing with the power system contractor, Johnson Controls, Inc. (JCI), regarding specific requirements. Mutually agreeable requirements were identified and met prior to the demonstration.
- ***Necessary third party notifications:*** According to site personnel, none are needed.
- ***Environmental constraints:*** The site environmental controls office has been consulted. GE has received verbal approval; site personnel may have written documentation.
- ***Health and safety:*** Site documents have been received and are under review by GE. Compliance with both site and GE standards are maintained.
- ***Existing interconnection requirements:*** There is no interconnection requirement that directly affects the testing and demonstration of the microgrid controller. However, the microgrid controller can provide better solutions if the Base can export power to the utility grid during periods of low load and higher available generation – a service that is not in place yet. Twentynine Palms energy manager is working with the utility to negotiate this aspect. There also is a minimum

import requirement which needs to be met all through the year; or a penalty will be incurred.

5.0 TEST DESIGN AND ISSUE RESOLUTION

The fundamental problem addressed by this project is improved energy surety. Heavy reliance upon imported power degrades energy surety, thus this project develops and field tests techniques to reduce reliance upon import power. Energy surety also improves as local power generation assets are fully utilized. At MCAGCC, there is room for improvement in both areas. This demonstration assessed the degree to which the MCS can effectively improve local generation efficiency and local power source integration. In addition, the demonstration provided data necessary to assess how well the MCS handled energy surety aspects both during grid-tied as well as islanded operation. Impact on the operator work load was also be assessed.

5.1 BASELINE CHARACTERIZATION

Baselines are required for all of the data mentioned in Section 5.1.

- ***Reference Conditions:*** The data collected included:
    - PV power output, power factor and voltage.
    - Co-Gen power output, power factor and voltage.
    - SCE power imported through Ocotillo, power factor and voltage.
    - Loads per feeder in the Co-Gen switchyard (including load per phase).
    - Loads at each temporary building (including load per phase).
    - Performance data for each controllable microgrid asset (response times, states before and after the control event).
    - Operator performance data for operator-initiated events (response times, states before and after the control event).
- ***Baseline Collection Period:*** Some of the required data was collected regularly at the base. To the extent possible, this data will be used. Data that is not normally archived were collected over a three month period.
- ***Existing Baseline Data:***
    - PV power output, power factor and voltage.
    - Co-Gen power output, power factor and voltage.
    - SCE power imported through Ocotillo, power factor and voltage.
    - Loads per feeder in the Co-Gen switchyard. Per-phase load data is not available.
    - Transition to islanding standard operating procedure.
- ***Baseline Estimation:*** Baseline estimation will only be used to replace bad or missing data. In all cases, estimations are based on other historical data. The algorithms used were developed at GE-Global Research using system data previously provided by Twentynine Palms.

- ***Data Collection Equipment:*** All data originated either in the controllable asset, or in the associated relay. No specialized sensors were needed.

5.2 DESIGN AND LAYOUT OF SYSTEM COMPONENTS

- ***Controllable assets*** key to microgrid management include:
  - The CHP unit
  - Boilers (either manual or automated control, as available)
  - Buildings: These can be controlled by Cimplicity and/or Computerized Electric Systems (CES) smart panels.
  - Legacy assets: The MCS will control those via the existing control systems.
    - Central Control system (CCS): A Rockwell (Allen-Bradley) controller.
    - Energy Management Control System (EMCS): JCI Network Automation Engine (NAE).
- ***System Components:*** This demonstration was intended to collect data sufficient to model all the MCSs capabilities. The central physical components were:
  - The communication hub, operating in a Dell server
  - The Optimal dispatch engine, operating in a Multilin Universal Relay 90+ (UR90+)
  - Initial building load management set up, can be done either from the GE Cimplicity layer or by operating a GE device called C90. At this point, the former approach is taken.
- ***System Integration:*** The MCS leveraged the existing EMCS and CCS control systems. With the exception of adding the capability to communicate with the MCS and execute MCS commands, the existing EMCS and CCS was not changed. The MCS failure path shifts microgrid control to the existing systems. In addition, the MCS included an advisory state, where recommended MCS actions are displayed on the HMI, but operators remained in control.
- ***System Controls:*** Visibility into, and operator interaction with, the MCS were provided through the existing operator's console. Figure 4 shows one of the screenshots of some of the system information provided on controllable assets.
- ***Data Collection:*** Baseline and new performance data were collected from April until November 2012 for the current phase report. However, GE and the Base are very interested to continue collecting data beyond the current phase. The performance results will be provided to DoD periodically.

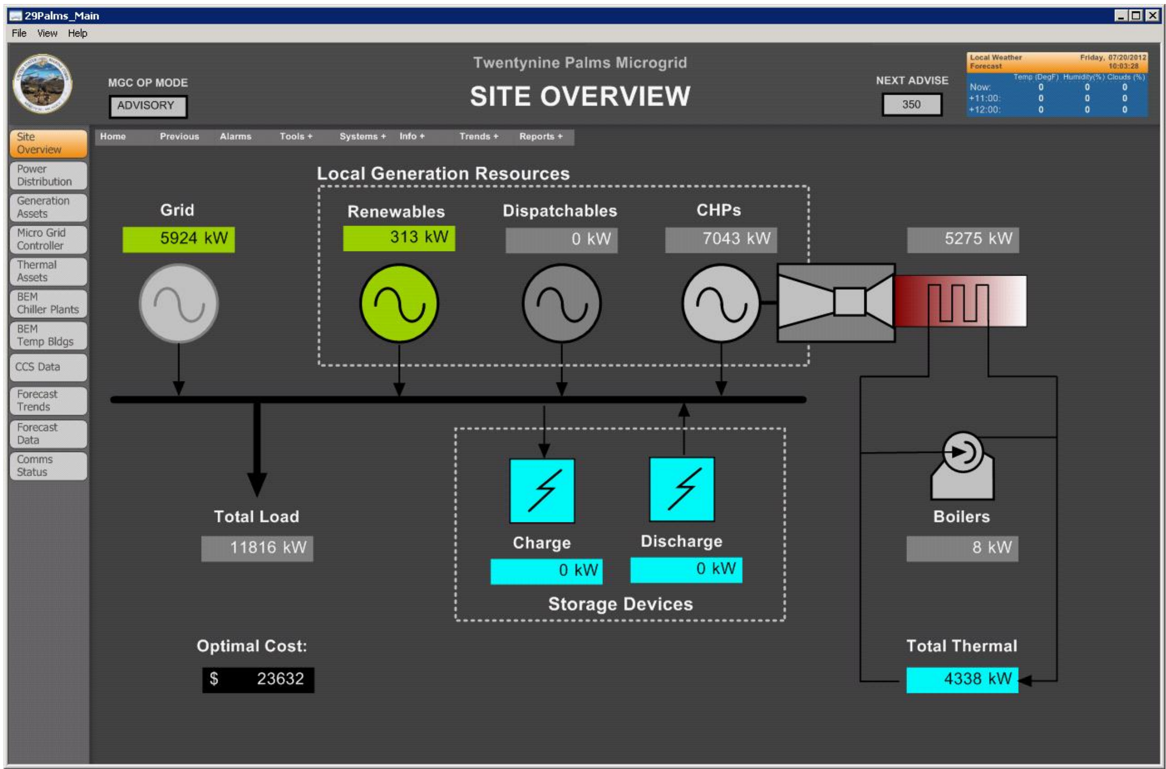

Figure 3. MCS site overview screen.

5.3 OPERATIONAL TESTING

Testing consisted of the following phases:

- MCS Advisory Mode tests conducted were:
  - Set all MCS controllable assets to Advisory Mode.
  - Confirmed that the MCS data logger and universal relay data loggers were active.
  - Confirmed that all inputs into the MGC were correct.
  - Continuously monitored the system.
  - Make regular backups of the data.
- MCS Auto Mode tests conducted were:
  - Made a final backup off Advisory Mode test data.
  - Cleared data logs.
  - Set all MCS controllable assets to Auto Mode in U90+ without making final connection with the end equipment with Cimplicity.
  - Monitored system operation over long period of time.
  - Verified that the MCS was correctly optimizing microgrid operation.
  - Made regular backups of the data.

- The final connection of its commands to the actual equipment was being planned after the Base engineers learned operation of the controller and the fallback features.

- Load Management Test Procedure:
  - Confirmed that the MCS was operating in full-auto, grid-tied mode.
  - Sent signal to Cimplicity (as if islanding was taking place).
  - Tested the MGC changing the mode for isochronous operation.
  - Tested that the load management section in Cimplicity sent out commands to the loads (building thermostats).
  - Load controllers execute the command.
  - Measured the specific load profiles before, during and after the event.
  - Reconnected the loads back on after 60 minutes and continued collecting data for some more time to make sure all thermal loads were properly accounted for during this event.
- Data collected during active testing were used to model the Twentynine Palms microgrid in the General Electric-General Research (GE-GR) Smart Grid lab, to the level it was deemed appropriate for testing and validation. This was extensively described in Appendix A of the Final Report.

At the close of testing, the DoD will be given the option to retain the equipment and control system. If that option is exercised, then GE will provide materials such as manuals, schematics, etc. suitable for day-to-day operations. GE-GR is not a production facility, and does not provide long-term operational support. However, all equipment provided is commercially available hardware and post-project support was available through the vendors.

6.0 PERFORMANCE RESULTS

The performance objectives presented in this section define the specific means by which this project meets its goals. Data collected during the demonstration will provide the information necessary to assess the effectiveness of the various strategies used. A third qualitative objective, scalability across the DoD will be a benefit, but no attempt will be made to definitively quantify it. The tools, techniques and strategies demonstrated will be applicable to almost all power delivery systems, regardless of size.

Performance objectives are described in Table 1 of Section 3. Each objective has a specific metric, data requirement and success criteria. The following subsection describes the performance results for each of them.

6.1 INCREASED ENERGY EFFICIENCY

The performance objectives quantify the effectiveness of the MCS to manage electrical and thermal energy within the microgrid. This is expected to provide higher benefits than managing the electrical energy all by itself, especially when one primary distributed energy resource is a CHP unit which can generate both electricity and heat. To determine the efficiency improvement, the data requirements included: the NG consumption by the Co-Gen as well as the boilers of the HTHW system, the active and reactive power produced by the Co-Gen, and the input/output temperatures and flow rates within the HTHW system. Comparing with using multiple DERs and boilers used to meet the same demand, it is expected that the microgrid controller could show up to 2-3% efficiency improvements over the year in a microgrid like Twentynine Palms that has a few boilers and one CHP. This number was expected to increase 10-15% with more CHPs and energy storage. This will be extrapolated (as described in section 6) to obtain an estimate of overall increase in energy efficiency possible across a DOD Base, by the technology developed in this program.

Figure 4 shows the results of the optimization explained above. First the optimization was started at the nominal heat and electricity outputs from the CHP. The optimal cost output for this case is considered 100%. Initially, to meet the thermal demands, the heat output was given a higher preference till all the thermal demands were met. However, the electrical command goes away more from its nominal output and the optimal cost increased, which implied that this trajectory (red lines) is not optimal. From this point, the heat output was kept constant but the electrical output was given a higher preference. By doing this, the CHP electrical command started rising and came back more towards its nominal rating, and the optimal cost started coming down (green lines). Finally, the lowest feasible optimization output was found, which maximized CHP electrical command with lowest optimal cost. This gave the right heat-electricity ratio for the thermal load and the optimal cost was typically 2-4% (2.1% in Figure 4) below the 100% cost output obtained with the nominal heat-electricity ratio for the CHP. Once this split of thermal versus electrical outputs was decided by the process described above, the system can be kept constant throughout the season till the thermal load changes considerably.

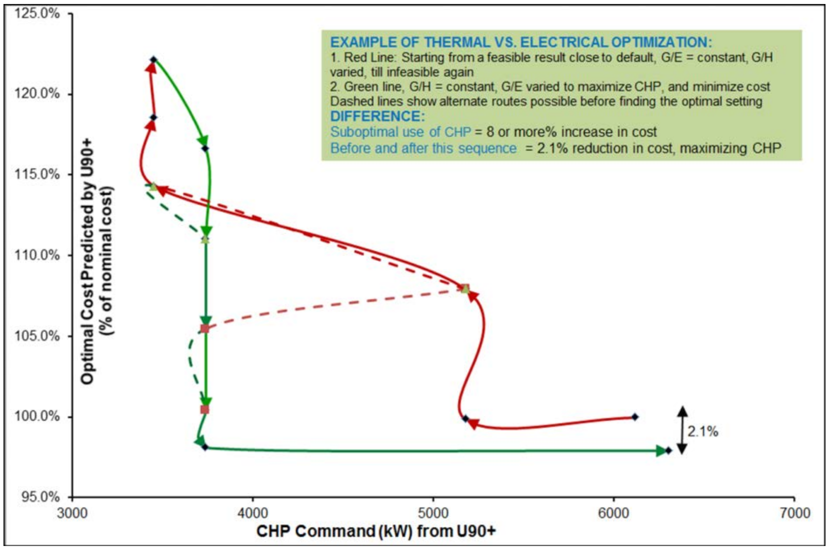

Figure 4. Results of optimizing thermal and electrical outputs of a CHP unit.

Thus we can conclude that microgrid controller can optimize up to 2-3% efficiency improvements over the year in a microgrid, like Twentynine Palms with a few boilers and one CHP. This number is expected to increase to 10-15% with more CHPs and energy storage and will be validated in Phase 2.

6.2 INCREASED ENERGY SURETY

This project has demonstrated capability to control loads from the centralized microgrid controls. Twentynine Palms was chosen to demonstrate that non-critical loads in the building could either be completely turned off (e.g., unnecessary lighting) or turned down (e.g., by increasing the thermostat settings on a hot summer day without sacrificing comfort). Load shedding in this project consisted of building compressor settings and opening and closing breakers at individual buildings. Because Twentynine Palms MCGACC is an operational military facility, access was not given to all the loads. Though this test was conducted in one major building (PWD building), it can be replicated for any other building loads. By controlling the non-critical loads, it is expected that critical loads can be serviced longer during an islanding event.

The goal of this test was to demonstrate the capability of reducing loads at the building level. During the islanding events or other major disturbances, the Base has capability to drop one feeder at a time (based on predetermined priority) or half of one particular feeder using recently installed motorized breakers. This test showed that the MCS developed in this project can reduce loads quickly at building levels, if deployed widely. As shown in Figure 5, a sizable amount of electric load can be dropped instantly by managing the building loads without sacrificing too much comfort. In this building 33% of the load reduction is possible under the current scenario. In some cases the drop could be lower, and in some cases the whole building could be dropped (if it was not essential to provide service). However, on an aggregated feeder level 10% of reduction of aggregated loads is possible (assuming one-third of the buildings participate in these tests) in just a few seconds to 10-15 minutes timescale without tripping the whole building or sacrificing too much comfort.

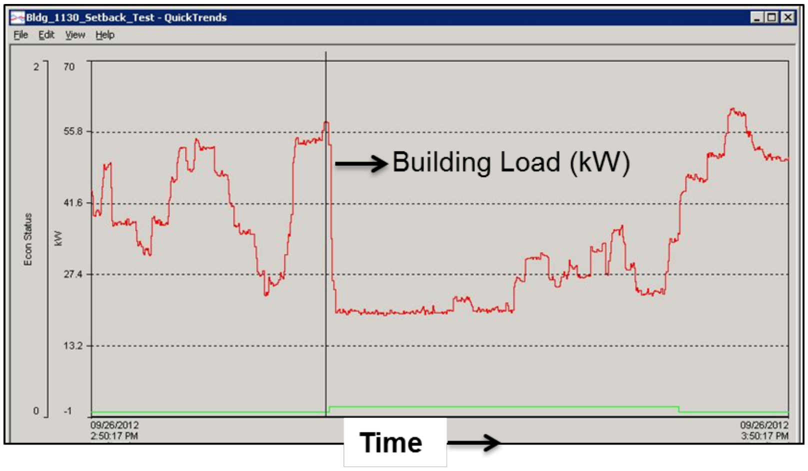

Figure 5. Dropping building loads from MCS for one hour.

It could also be noted that after some time the load will rebound as the thermostatic loads like air-conditioners come back stronger to cater to the rise in temperature in this period. So one has to be careful to calculate the benefits on energy savings based on tests like this and more data is needed to do so. The purpose of the test is not to show energy savings benefits but possible amount of load reduction available in quick time at the building level to give some momentary relief to the distribution. To make sure that the Cogen is commanded to pick up 100% of the critical loads, islanding data from January and February 2012 were played back in real time at GE to make sure that the CHP command quickly caught up with the actual load after grid power went down.

6.3 INCREASED RENEWABLE ENERGY USAGE AND REDUCED FOSSIL FUEL USAGE

Operability of renewables is given the highest priority in the microgrid objective function. Before optimizing other distributed resources, PV (in case of Twentynine Palms) gets the highest priority in the Unit Commitment. This will be true even during Islanded mode operations. While it is hard to quantify the "maximum utilization" or renewables since it depends on available sunlight, the project will estimate potential displacement of fossil fuel based generation by using renewables and other NG based DERs and calculate GHG emissions reduced.

To evaluate this feature, several experiments were conducted in the GE laboratory; and the difference in cost with and without renewables during a whole day was noted to determine the effect of the renewable energy contribution on optimal cost. Care was taken that for the case that did not use renewables; they were disabled before sunrise and re-enable only after the sunset in that day. As seen in the Table 2, the optimal cost increases up to 5.4%. Later offline calculations showed this was roughly the amount of energy that renewables would have provided in that day if they were not disabled. This shows that the microgrid controller optimization takes into account 100% of the renewables available in a given day.

Table 2. Test results showing effect of renewable integration.

Test Condition	Optimal Cost (%)
System running with renewable (PV) enabled.	100.0
Output from next dispatch cycle after renewable are disabled at 6:45 a.m. (sun just coming up).	104.7
Output at 10:30 p.m. after the full PV cycle. Peak PV during the day was 865kW.	105.4
Output from next dispatch cycle after renewable are re-enabled at 10:30 p.m.	100.1

6.4 USER SATISFACTION

Reduced operator involvement during operations is a metric that measures the effectiveness of the MCS to manage the complex interaction of electrical and thermal energy within the microgrid. The MCS will include an operator event log, which will enable the capture of the interaction of the operator with the MCS. User satisfaction is guaranteed by co-locating the operator interfaces through bigger visual inputs and seamless operation from one screen to another.

6.5 REGULATORY AND END-USER ACCEPTANCE

Regulatory and end-user acceptance are always key challenges for any new technology and microgrid is no exception. During the training and demonstration phase, this project aims to show how microgrid can be a “win-win” proposition between regulators and end-users. The team will organized a series of demonstrations and outreach events, participated in conferences and workshops and through their interactions with the utility/regulators and other key stakeholders for microgrids in the DoD sector, influenced regulatory and end-user acceptance. To energy utility stakeholders and regulators, GE and the Base personnel presented the project in several conferences and workshops across the country. GE has also started using news media and blogs to receive feedback and acceptance on this technology – these will be discussed in details in Section 9. GE Global Research has started conducting regular “microgrid lab demos” with utilities worldwide whenever such an event is organized.

7.0 COST ASSESSMENT

7.1 COST DRIVERS

Cost of several microgrid elements at Twentynine Palms will consist of hardware, software and installation costs. The cost model is shown in Table 3.

Table 3. Cost model for microgrid control system.

Cost Element	Data Tracked During the Demonstration	Estimated Costs
Hardware capital costs	Estimates made based on component costs for demonstration	$150,000
Installation costs	Labor and material required to install. Included are the labor and travel costs for GE personnel to visit the Base	$20,000
Set up and commissioning costs	Labor and material required to select correct settings and parameters of the controller, testing and retune them as needed.	$100,000
Consumables	Estimates based on rate of consumable use during the demonstration	None
Facility operational costs	Reduction in energy required versus baseline data	$4-7M over 20 years. Explained in Section 6.2
Maintenance	• Frequency of required maintenance • Labor and material per maintenance action	$5000 per year for GE personnel to visit Base or answer phone calls for trouble-shooting. $10,000 once every 5 years for license upgrades.
Estimated salvage value	Estimate of the value of equipment at the end of its life cycle	Minimal
Hardware lifetime	Estimate based on components degradation during demonstration	Since industry grade equipment is used, 20 years life expectancy is estimated.
Operator training	Estimate of training costs	An average training cost of $2000 is assumed per year which included upgrade of user manuals, operation manuals etc.

A lot of uncertainty might come up while using the installation, set up or commissioning costs for another microgrid facility. These costs are highly dependent on available infrastructure, existing communication equipment and available personnel to support these activities. The costs estimated in Table 4 were based on the already available infrastructure and excellent support given by the Base engineers and their energy service provider (JCI).

7.2 COST ANALYSIS AND COMPARISON

An estimate of lifecycle cost and payback calculations were done using the National Institute of Standards Technology (NIST) Building Life-cycle Cost (BLCC) model to explain life cycle costs

for the MCS. This section will show the input and output results of the model to determine costs and benefits of this technology.

A glimpse of the BLCC model as shown in Figure 6 uses the Federal Analysis, Financed Project module for a Life-cycle cost (LCC) analysis of energy savings in energy or water conservation projects funded by the Federal Government. Six alternatives are considered for cost analysis and comparison. They are:

1. Baseline – this is based on available yearly energy consumption data from the Base.
2. Optimal Dispatch Technology with minimal assets – this assumes about 2-3% energy efficiency benefits as described in Section 6.
3. Optimal Dispatch with all assets – i.e., additional CHPs, fuel cell, energy storage, etc.
4. Load Management – benefits of energy efficiency on load management is considered.
5. Optimal Dispatch and Load Management combined.
6. Optimal Dispatch with Renewables – only to determine the GHG emission reduction.

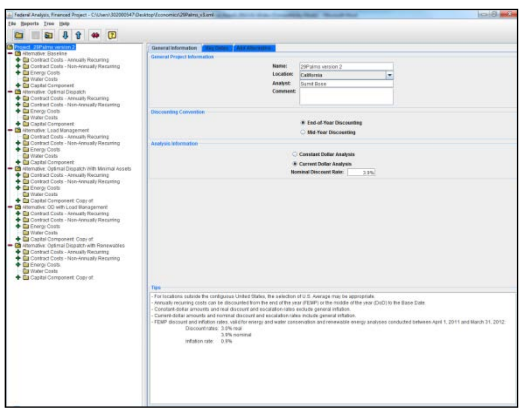

Figure 6. BLCC model for Twentynine Palms microgrid.

Based on these outputs and following NIST guidelines, savings to investment ratios (SIR) and annualized iternal rate of return (AIRR) are calculated for some of these alternatives and GHG benefits for renewables. Table 4 summarizes these results.

Table 4. Cost benefit summary.

Case	SIR	AIRR	Total Savings	% Energy Used	Emission (Tonnes/year) CO_2	SO_2	NO_x
Baseline, Twentynine Palms (estimated)	NA	NA	$0	100%	71948	479	95
Optimal dispatch with minimal assets	6.59	13%	$4,218,818	98%	51733	314	51
Optimal dispatch with all assets	11.54	16%	$7,386,162	98% for 3 years, 95% for next 9 years, and 90% thereafter	51176	314	51
Load management only	2.05	7%	$3,682,421	99% for 4 years, 98% for next 5 years, 96% for next 5 years, and 95% thereafter	51596	314	51
Optimal dispatch with load management	4.19	11%	$8,465,257	97% for 3 years, 93% for next 6 years, 91% for next 3 years, 85% thereafter	50783	314	50
Optimal dispatch with renewables	Not calculated, varies for different types of renewable resources and their costs.			93% for 3 years, 90% for next 9 years, 85% thereafter	50538	314	50
Difference in emission (baseline with renewables)					21410	165	45

There is an interesting point to be mentioned on Table 4. Optimal Dispatch with Load Management shows higher energy savings than Optimal Dispatch with All Assets. It is assumed that the buildings may need special controls and building energy management system to interface with the microgrid controller in order to achieve this. This project used the existing building energy management system from JCI, but in the above table some cost is assumed per building, which also rises with more buildings. This rise of initial upfront cost is higher than the benefits realized later from energy savings; hence, this shows lower AIRR and SIR compared to the optimal dispatch, which saves lower energy than when coupled with load management but the upfront cost is also relatively less.

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8.0 IMPLEMENTATION ISSUES

The project had a relatively seamless implementation and system integration during the demonstration phase due to excellent camaraderie and support provided by the Base engineers and members of their JCI. Without their cooperation and team work, this project would not have reached this stage of success.

There are a few lessons learned that are listed below, which can aid future implementation of the technology.

1. The Base is not allowed to export excess power generated by its DER to SCE beyond a very small threshold. Negotiations are currently going on between the two sides to see if this limitation can be lifted so that more value can be derived of the MCS.
2. Time of use or real time pricing scheme can enhance energy efficiency benefits at certain points of the day and the optimization can provide appropriate commands depending on the price of electricity. All the current benefits discussed in this report are based on a single average electricity rate.
3. MCS can take into account and do continuous set-point control of diesel gensets. But this feature was never implemented due to USEPA regulations that allow operation of these gensets only 200 hours in a year (other than emergency operations). Hence, they are reserved for maintenance related events only.
4. The project was delayed due to fiber optic installations across the Base that will enable, MCS to be aware of all the other substations and their loads, outside the AA substation at Twentynine Palms
5. Though testing has been conducted to make the U90+ work in automated mode, the final connection of its commands to the actual equipment is not made. This is being planned after the Base engineers fully learn operation of the controller and the fallback features.
6. Though the Base has a good size solar plant, it does not have the state-of-the-art interfaces. Therefore, external commands to control its active and reactive power outputs is not possible. Also there is large amount of distributed PV across the Base, but they are not aggregated or accounted by any existing data acquisition system.
7. The MCS works in a secure and dedicated network without access to external internet. Hence, any external weather forecast information is unavailable to predict thermal or electricity demands during the day. U90+ has incorporated its own forecasting routine using historical information. While this is expected as a standard practice for all DoD bases, this could be specified as a requirement in the initial design phase of the project.
8. The Base had a fuel cell that was not operational during the course of this project. This would have added extra capability in the optimizer. However, integration of a replacement fuel cell is planned in the next phase of the project.

9. The Base uses a few third party vendors as contractors for communication setup or testing islanding mode etc. Continuous coordination is necessary to work with the schedules of GE engineers, the Base engineers, JCI, and the third party contractors. Most of the time, this did not impact much on the project schedule.

9.0 TECHNOLOGY TRANSFER

9.1 COMMERCIALIZATION AND IMPLEMENTATION

GE has two businesses under this program and both are very interested in taking the technologies developed by GE Global Research to market. First, GE Intelligent Platforms provides world class commercial control software in their Proficy suite. Proficy quickly integrates information from across a facility to gather, correlate and interpret critical business intelligence efficiently. It also helps trace process and product data, providing an accountable and up-to-date status of operations at any time. Second, GE Digital Energy provides products including distribution automation controllers, which allow utilities to monitor and control assets, maximizing the flow of electricity and increasing service reliability.

GE Global Research has already engaged both businesses, through the prior relationship with DoD ESTCP and will continue to work with those businesses, if awarded this proposed program. The method by which the technology will be transitioned to the DoD end user(s) involves the actual usage of the MCS on the base's identified microgrid via GE Digital Energy (microgrid controller and Volt/VAr control) and GE Intelligent Platforms (supervisory controller, the HMI, the BEM, and certified network communications) hardware and software tailored for Twentynine Palms operation.

The method by which the technology will be transitioned to the DoD and other end user(s) involves the actual usage of the MCS on the Base's identified microgrid. This will be done via GE Digital Energy (microgrid controller) and GE Intelligent Platforms (supervisory controller, the HMI, the BEM, etc.) hardware and software tailored for the Twentynine Palms operation. Key commercialization and technology transfer strategies can be:

1. There are DoD forcing functions to further utilize the GE microgrid technology across DoD bases, for example, Army, Air Force, and Navy mandates to install three gigawatts (GW) of renewable energy on DoD bases by 2025. The technology developed in this project is scalable across all these DoD installations.
2. DoD is developing an integrated, enterprise-wide data management approach for all of its facilities that incorporates electric metering. According to the DoD Annual Energy Management Report for FY2010[3], cumulative percentage of buildings across DoD installations with electric metering is 95%. The GE technology is not only structured to use GE hardware and software for the microgrid, but is also capable to utilize inputs such as building energy management systems from vendors such as JCI.
3. GE will specify the technology transfer method for the appropriate audience, spanning from regular campus microgrids to military bases to remote communities.

9.2 TRAINING REQUIREMENTS AND RESOURCES

GE Engineers are constantly engaged with the Base engineers and operators to make sure that the technology is well understood and utilized by them. A few ongoing efforts worth mentioning on this topic:

- GE has prepared a detailed instructional manual for the U90+ controller. This will provide great insight to anyone learning to operate the system. A shorter and simpler operation manual is also being prepared.

- GE Global Research has a blog site where information about the projects is posted. GE Digital Energy has also recently started working with the media to provide short excerpts of information about commercializing the microgrid controller. Figure 7 shows a screenshot of the blog and Figure 8 shows a screenshot of the GE Digital Energy News and Events website describing GE's future offering on this technology.

Figure 7. GE Global Research Blog.

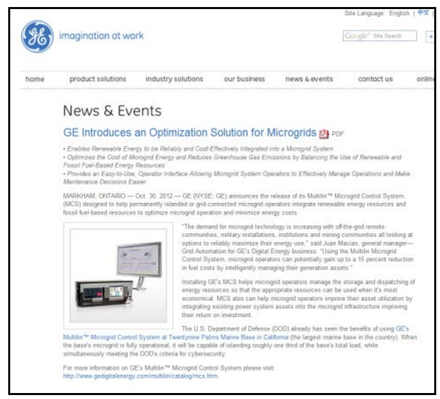

Figure 8. GE Digital Energy News Article.

- GE and the Base personnel have presented the project at several conferences and workshops across the country. A list of the meetings attended during the course of this project are:
  - Twentynine Palms Microgrid Overview, Microgrid Exchange Group, May 2010
  - Microgrids for Installations, U.S. Air Force (USAF) Personnel Visit to GE, June 2010
  - Microgrids, GovEnergy, August 2010
  - GE Microgrids, TFT Network Energy, October 2010
  - "Microgrid Technologies – Twentynine Palms – Distribution Optimization in Smart Grids" – Symposium on Microgrids, Jeju Island, Korea, May 2011
  - Military Smart Grids & Microgrids Conference, May 2012
  - Department of Energy Microgrid Workshop, July 2012

- GE and the Base will continue to work with DoD to provide information to other DOD agencies, websites, etc., about this project.
- A position paper on microgrid energy management for military bases is planned for publication in IEEE and/or other peer reviewed journals.

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Project link in ESTCP website: http://serdp-estcp.org/Program-Areas/Energy-and-Water/Energy/Microgrids-and-Storage/EW-200937

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APPENDIX A

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Larry Krause	GE Intelligent Platforms	Phone: (518) 464-4520 E-Mail: larry.krause@ge.com	Manager, GE Intelligent Platforms
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